EXXON BACKGROUND SERIES

# Fate and Effects of Oil in the Sea

DECEMBER 1985

A background paper prepared by the Public Affairs Department of
Exxon Corporation in cooperation with other Exxon departments and affiliates.

# Fate and Effects of Oil in the Sea

## Table of Contents



## Figures



## Table

## 1 INTRODUCTION

Petroleum hydrocarbons—oil—enter the marine environment from a variety of sources, both through natural phenomena and man's activities. Seeps and erosion of geological sediments contribute petroleum hydrocarbons to the environment through natural processes. Man releases oil in many ways, including accidental spillages, long-term, low-level discharges associated with municipal and industrial wastes, petroleum production, and transportation activities.

Organisms living in the sea also produce hydrocarbons through natural biological processes. Some of these hydrocarbons are identical in chemical composition to petroleum hydrocarbons. There is little doubt that such biologically produced hydrocarbons experience similar fates as petroleum hydrocarbons and have similar effects on the marine environment.

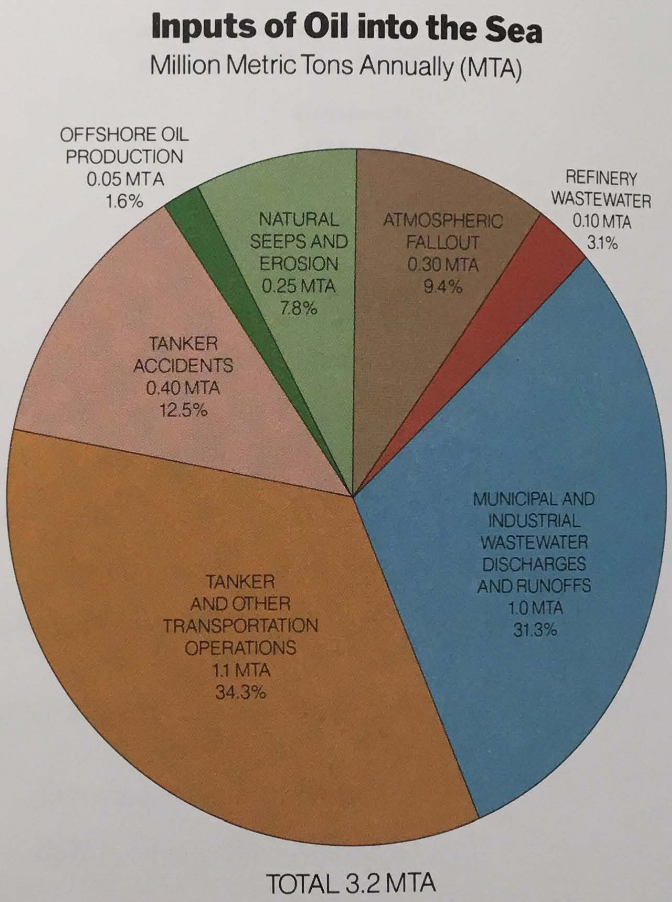
Just as nature and man contribute to the introduction of oil into the sea, both contribute to its removal or its dispersal into innocuous concentrations. Natural processes – physical, biological, and chemical – degrade the petroleum hydrocarbons. Man, in a more direct approach, attempts to contain, recover, or chemically disperse oil released into the sea, particularly after primary efforts at prevention may have failed.

Too much petroleum at any one time or in any one place can be detrimental to marine life and can be aesthetically unpleasant. It is, therefore, important to know of such occurrences and what the consequences are. This paper attempts to provide some answers based upon the considerable amount of scientific study that has gone on in this field over the last decade.

## 2 INPUTS OF OIL INTO THE SEA

The U.S. National Academy of Sciences (NAS), in an assessment on petroleum pollution published in 1985[1], estimated that between 1.7 and 8.8 million metric tons per annum (mta) of oil enter the world's oceans. Within this range, 3.2 mta is regarded as the best single estimate—equivalent to only 0.1 percent of the total oil produced annually worldwide (approximately 3 billion metric tons).

Figure 1




Source: National Academy of Sciences, 1985.

Figure 1 illustrates the different amounts of oil introduced into the sea from many sources. Approximately one-third of the total petroleum entering the sea originates in municipal and industrial (excluding oil refineries) wastewater discharges, urban and river runoff, and ocean dumping. Another one-third comes from tanker and other maritime transportation operational activities. Of the total input, accidental spills from tankers account for about one-eighth. Atmospheric fallout (from trace amounts of petroleum which had evaporated into the atmosphere) accounts for less than 10 percent, as do natural

seeps and erosion. The remainder comes from petroleum refineries (3 percent) and offshore oil production (less than 2 percent).

Table 1 compares these estimates with those published by NAS in 1975[2]. All categories except spills show about a 50 percent decrease. According to the NAS, part of the reduction in most of the categories is attributed to refinements in estimating techniques. However, other reductions are believed due to efforts to reduce oil pollution, such as the international effort to reduce tanker operational discharges. Because annual figures for marine accidental spills vary significantly, an average over a number of years was used for both the 1975 and the 1985 reports. The increase shown for such spills in the 1985 study reflects the influence of major incidents, such as the loss of the 220,000 deadweight-ton tanker *Amoco Cadiz*, which occurred in the period (1975 through 1980) used to calculate its annual average. In more recent years, industry statistics indicate, accidental spills from tankers have declined substantially.

Petroleum is not a substance foreign to the marine environment. Natural seeps have been discharging petroleum hydrocarbons into the marine environment for millions of years, in amounts substantially greater than those resulting, for instance, from present-day offshore production activities. About 200 submarine oil seeps have been identified around the world (Figure 2), and there is little doubt that many more exist. Petroleum has also continuously entered the seas as a result of the erosion of uplifted sedimentary rocks containing trace amounts of petroleum hydrocarbons.

Other hydrocarbons, generated by organisms living in the oceans and unrelated to petroleum, have also been detected in the water. While some of these biologically produced hydrocarbons are identical in chemical composition to petroleum hydrocarbons, others are chemically quite different. They range from gases (e.g., methane, ethane), through liquids, to solid paraffin waxes of high molecular weight, and there is no reason to believe that their behavior would not be comparable to that of petroleum hydrocarbons.

Most surface and near-surface open ocean waters contain petroleum hydrocarbons in the range of about 1 to 10 parts per billion (ppb), according to NAS' 1985 study. In deeper open ocean waters the concentrations are 1 ppb or less. (One ppb is equal to about one drop of oil in about 100,000 quarts of water.)

Coastal waters, particularly those near populated and industrialized areas where the presence of oil is more likely, show higher petroleum hydrocarbon levels (up to 100 ppb) than open ocean waters. These levels of concentration, however, appear to have little, if any, toxic effect on marine life. Laboratory experiments conducted to determine the toxicity of crude oils or petroleum products indicate that concentrations from 10 to 100 times greater than those of coastal waters are required before measurable effects on marine organisms can be detected.

Table 1

**Comparison of Petroleum Inputs from Different Sources**

*(Million Metric Tons Annually)*

| | 1975 Study[1] | 1985 Study[2] |
|---|---|---|
| Municipal and Industrial Wastewater Discharges and Runoffs | 2.5 | 1.0 |
| Refinery Wastewater Discharges | 0.2 | 0.1 |
| Offshore Oil Production | 0.08 | 0.05 |
| Marine Transportation | | |
| Tanker Operations | 1.3 | 0.7 |
| Accidental Spills | 0.2 | 0.4 |
| Other Maritime Activities | 0.6 | 0.4 |
| Natural Seeps and Erosion | 0.6 | 0.25 |
| Atmospheric Fallout | 0.6 | 0.3 |
| TOTAL | 6.1 | 3.2 |

(1) *Petroleum in the Marine Environment*, National Academy of Sciences, 1975.

(2) *Oil in the Sea: Inputs, Fates, and Effects*, National Academy of Sciences, 1985.

*Note: Estimates of annual petroleum inputs in both studies were based on data for several years prior to publication. The periods for which amounts of petroleum were estimated differed among the sources; for the 1975 report, most estimates were representative of 1973 while for the 1985 report they were for 1981.*

1 *Oil in the Sea: Inputs, Fates, and Effects*, National Academy of Sciences, Washington, D.C., 1985.

2 *Petroleum in the Marine Environment*, National Academy of Sciences, Washington, D.C., 1975.

Figure 2

## Locations of Natural Underwater Oil Seeps

*Dots indicate the locations of natural underwater oil seeps which have been identified to date around the world, according to the National Academy of Sciences. One dot off the California coast represents 54 individual seeps; another, in the Gulf of Alaska, represents 28.*

## 3 FATE OF OIL IN THE SEA

As described in the previous chapter, oil can enter the sea in a variety of ways ranging from large or small accidental releases, commonly referred to as oil spills, to the long-term, low-level inputs associated with natural seeps.

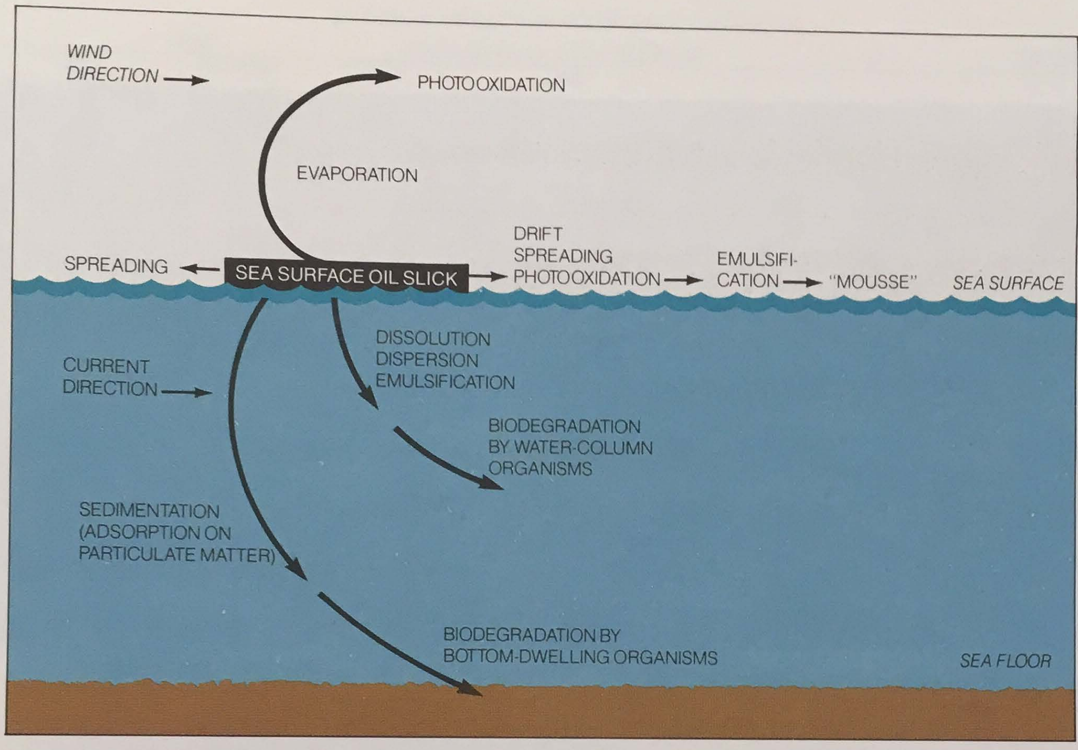
Over the years, both industry and governments have placed increasing emphasis both on preventing oil from entering the sea as a result of man's activities and on developing contingency plans to cope with oil spills when they occur. Expertise has been developed to contain and pick up oil accidentally released to the sea. Improved chemical dispersants have been formulated as another tool to aid in removing oil from the water's surface, either to supplement mechanical removal techniques or to use when mechanical removal is not feasible.

Even with all the efforts to prevent oil pollution and to contain, recover, and disperse accidental releases or oil slicks, however, petroleum hydrocarbons have entered and will continue to enter the marine environment. This chapter examines what happens to the oil over time after it enters the ocean and is not removed.

When oil enters the sea, whether in relatively large instantaneous spills or in long-term, low-level volumes, many natural physical, chemical, and biological processes occurring in the ocean act on the oil. Some of the processes are most important immediately after the oil is introduced; other processes become increasingly important as time goes on. Figure 3 depicts the processes occurring in the water, the overlying atmosphere, and the underlying bottom sediments. Figure 4 relates the time following discharge of oil into the sea to the various processes of movement and degradation. Line length represents the probable time span of

Figure 3

## Processes Acting on Spilled Oil




any process while line width indicates the intensity of the process through time and its relation to the other concurrent processes. Understanding of these processes continues to improve; thus, Figure 4 reflects more knowledge of process time spans and intensities through time than was available when the 1978 issue of this paper was published.

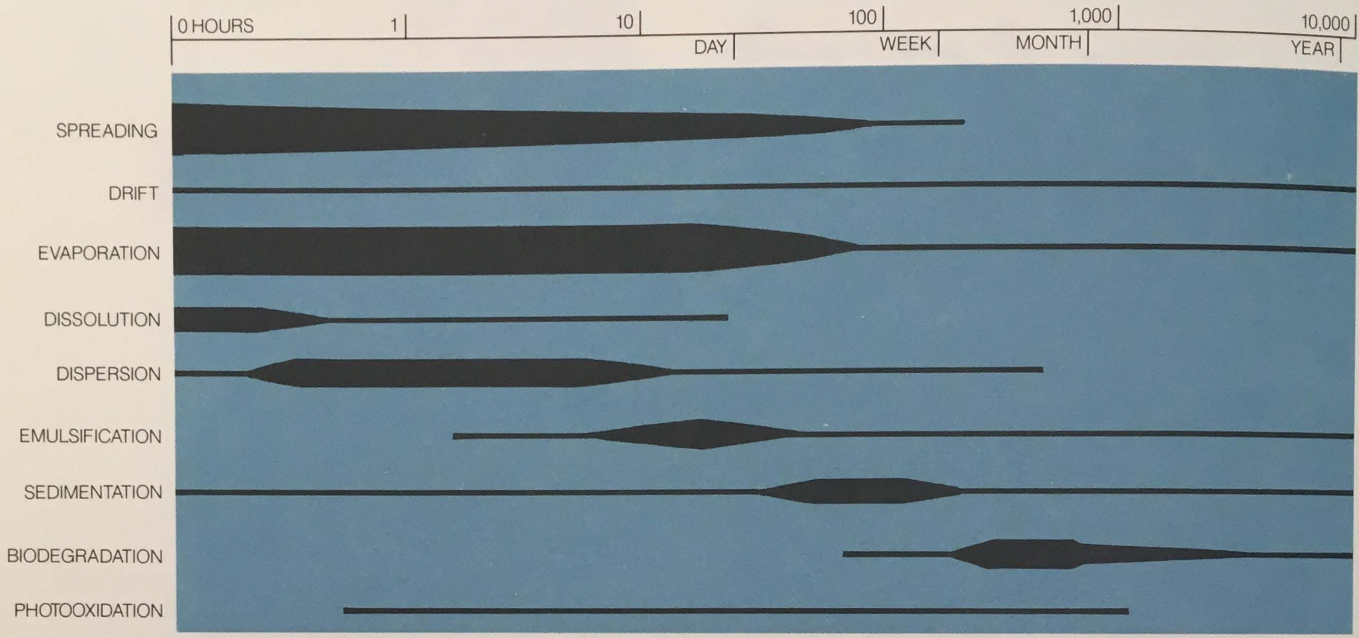
Spreading of an oil slick on the sea surface is a rapid and dominant process at the time of a release, decreasing steadily until it has essentially stopped within a week to 10 days. The process is controlled by the physical and chemical properties of the oil (such as viscosity, density, and wax content) and the environment (sea conditions, water and air temperature) into which it is released. Other processes, such as evaporation, dissolution, dispersion, emulsification, and photooxidation, are enhanced by spreading.

Drift, the movement of the center of a mass of oil on the surface of the ocean, is caused by the combined action of wind, surface currents, waves, and tides. With larger amounts of oil, such as occur with accidental oil spills, the oil drift is largely independent of spill volume, spreading, or weathering. Since the "thick" portion of the slick drifts faster than the "thin" portion, a heavy oil accumulation forms the leading edge of an advancing slick. The drift process is always active —from the moment oil is released into the sea until the oil disappears from its surface.

It is difficult to predict precisely all the complex interactions of oceanographic and meteorological factors which influence drift of an individual oil slick. However, field and laboratory observations of the drift of oil slicks are surprisingly consistent. The velocity and direction of movement of a slick depend on surface currents and wind velocity, and can be determined by the technique illustrated in Figure 5.

Figure 4

## Time Span and Relative Magnitude of Processes Acting on Spilled Oil




LINE LENGTH—PROBABLE TIME SPAN OF ANY PROCESS.
LINE WIDTH—RELATIVE MAGNITUDE OF THE PROCESS BOTH THROUGH TIME AND IN RELATION TO OTHER CONTEMPORARY PROCESSES.

Source: Exxon Production Research Company

Evaporation is the primary weathering process involved in the natural removal of oil from the sea and is particularly dominant soon after oil is released. It involves the transfer of hydrocarbon components from the liquid oil phase to the vapor phase (atmosphere). Estimates from major spills as well as experimental data indicate that evaporation may be responsible for the loss of up to 50 percent of a surface oil slick's volume during its life. Evaporation rates of oil at sea are determined by wind velocity, water and air temperatures, sea roughness, and oil composition.

Some of the light low-boiling hydrocarbons, such as benzene, toluene, and xylenes, which are rapidly lost through evaporation, are among the most toxic components in oil. Thus, their removal decreases the toxicity to marine life of the oil remaining on the sea surface.

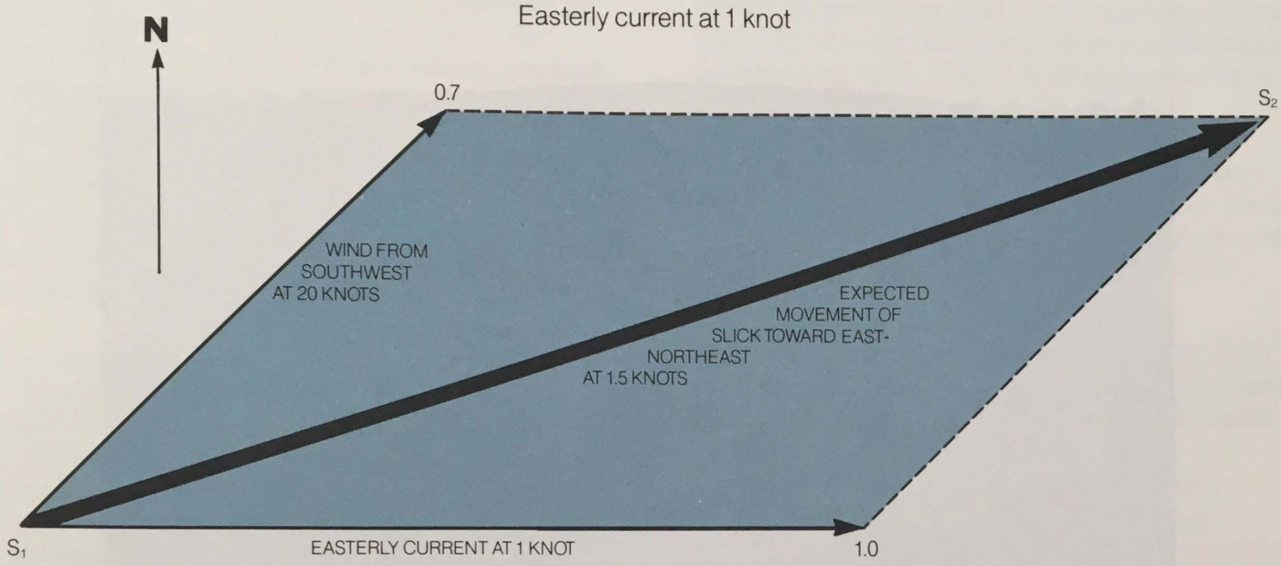
Much of the oil that evaporates is photooxidized in the atmosphere, but in the absence of good analytical data the contribution of this process cannot be estimated. It is reasonable to assume that some of the oil returns to the sea as atmospheric fallout (Chapter 2).

Dissolution is another early process acting on spilled oil. It involves the transfer of oil compounds from a floating slick, or from dispersed oil droplets, into solution in the water phase. Lower molecular weight compounds tend to be the most soluble. It is unlikely, however, that dissolution significantly affects slick weathering as only a very small fraction of the oil dissolves. Evaporation proceeds much more rapidly than dissolution.

Figure 5

**Technique to Determine the Resultant Velocity and Direction of an Oil Slick**

Example: Wind from southwest at 20 knots
Easterly current at 1 knot




*This simplified drawing illustrates a technique for determining the velocity and direction of movement of an oil slick by means of a mathematical calculation involving the surface current and 3.5 percent of the wind velocity. In this example, wind impacting on a slick at point $S_1$ is assumed to be coming from the southwest with a velocity of 20 knots. It, therefore, would tend to push the slick to the northeast at 0.7 knot. At the same time, the surface current would tend to push the oil to the east at 1 knot. Both forces combined, according to this calculation, would move the slick from $S_1$ toward $S_2$, or in an east-northeast direction, at 1.5 knots.*

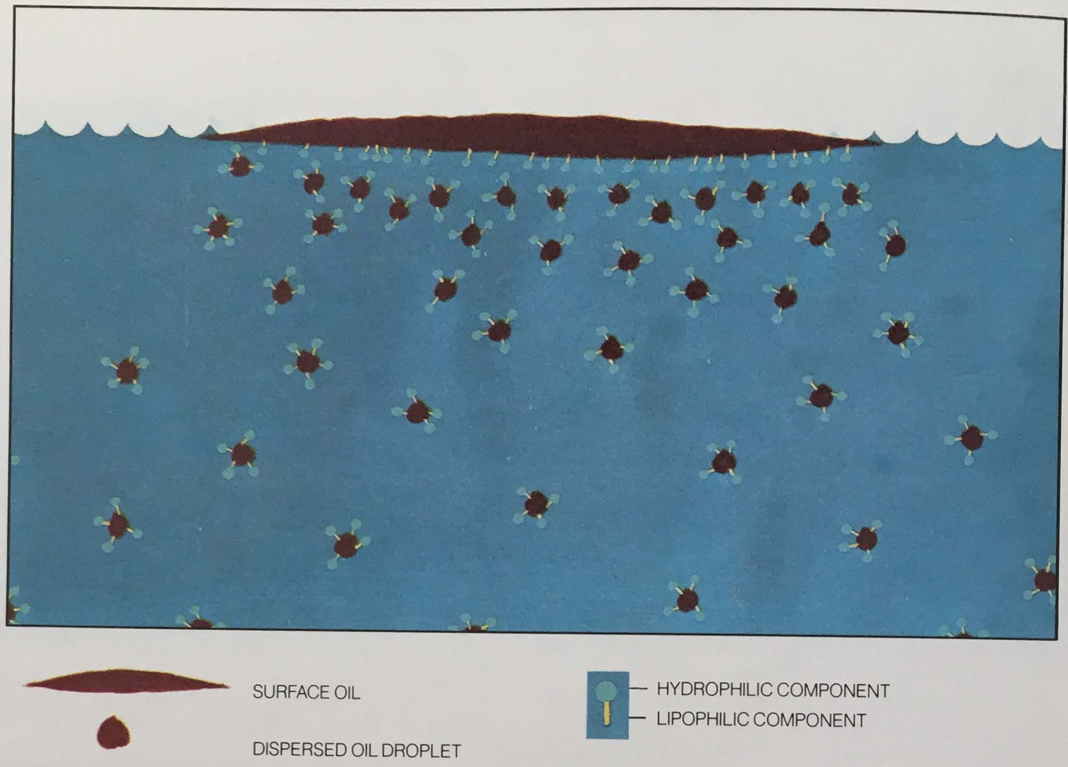
Oil also enters the water in forms larger than dissolved molecules. In natural dispersion, small droplets of oil (ranging in diameter from very small fractions of a millimeter to a few millimeters) are incorporated into the water in the form of a dilute oil-in-water suspension. Natural dispersion reaches a maximum rate in only a few hours (4 to 10) following a spill but continues for some time.

Oil dispersion is influenced by oil composition (e.g., wax and asphaltene content), density, viscosity, oil-water interfacial tension, and water turbulence. Crude oils and many petroleum products contain trace amounts of nitrogen, sulfur, and oxygen-bearing organic compounds which can act as natural surface active agents (surfactants). These surfactants reduce the oil-water interfacial tension, allowing the oil to break up and to disperse into droplets more readily. Chemical dispersants may be applied to an oil slick to supplement the natural surfactants, thereby enhancing the dispersion process. Figure 6 illustrates how an oil slick on the water surface is dispersed by surfactants, either natural or synthetic.

The primary purpose for removing oil from the surface through dispersion is to enhance the degradation process. The increase in the surface area of dispersed oil droplets resulting from surfactant action accelerates the degradation of the oil. Accelerating the dispersion process through the use of chemical dispersants also reduces the threat of floating oil stranding on a shoreline, where it can damage biota and property.

Figure 6

## How Surfactants Disperse Oil




*Surfactants are able to remove oil from the sea surface because their molecules are comprised of both hydrophilic (water compatible) and lipophilic (oil compatible) components. These properties cause surfactant molecules to orient themselves at the oil-water interface so that they are partly in the oil and partly in the water. As a result, the oil-water interfacial tension is reduced, breaking up the oil slick into minute oil droplets that become dispersed, as shown.*

Emulsification (water-in-oil) is a process in which water is incorporated into the floating oil. Such emulsions, which may contain from 20 to 80 percent water, are often very viscous and referred to as "mousse." Mousse formation is highly dependent upon oil composition; high levels of asphalt-type compounds, as well as waxes, appear to promote the formation of these emulsions. Ocean turbulence also accelerates mousse formation, although a fully developed, stable emulsion may be formed from some oils under relatively quiescent open water conditions. Early treatment of spilled oil with chemical dispersants is an excellent way to prevent emulsification.

Once emulsification does occur, certain demulsifier chemicals (used on collected mousse) can cause the oil and water to separate rapidly, thus facilitating transfer of the oil, disposal of the separated water, and a reduction in storage volume requirements.

Sedimentation involves the association of oil with sediments on the seafloor or with sedimentary particles suspended in the water column. Extensive oil contamination of subtidal seafloor sediments, to illustrate the former, has been reported following several spills which occurred during storms. The association of oil with suspended sediment particles can cover a range of sediment types, including organism shells, clay, silt, and sand. This mechanism is very important under shallow, rough sea conditions where bottom sediments are resuspended.

Some organisms may ingest dispersed oil droplets in the water column and subsequently deposit them as fecal pellets. In some cases this has been estimated to be a significant sedimentation process.

Biodegradation is another important process for removing petroleum hydrocarbons from the marine environment. All surface waters, fresh or marine, contain natural populations of bacteria, yeast, and fungi capable of metabolizing and chemically degrading petroleum hydrocarbons through their normal life processes. These organisms are also primarily responsible for degrading most of the biologically produced hydrocarbons introduced into the sea.

The rate and extent of biodegradation depend on the abundance and variety of existing hydrocarbon-degrading microorganisms, their predators, available oxygen and nutrients, temperature, and oil composition. Hydrocarbons, dissolved or dispersed in the water, are the most easily degraded; degradation of hydrocarbons contained in bottom sediments also occurs if oxygen is present. Emulsified oil (mousse) is slow to degrade because water is trapped within the emulsion and the nutrients and oxygen essential to biodegradation are kept out.

The exposure of oil to air and sunlight in a slick with a large surface area leads to photochemical oxidation (photooxidation). This process is dependent on the intensity of sunlight, temperature, and the chemical composition and the physical state of the oil on the water surface. Thin films oxidize more rapidly than thick oil or mousse. At the sea surface photooxidation occurs fairly rapidly – from a few hours to days – after the initial spill. Studies have shown that as much as 40 barrels spread over a square mile of ocean surface could be degraded in a few days by photooxidation, given adequate sunlight. (Forty barrels of oil spread over a square mile would create an oil layer about one-ten thousandth of an inch thick.)

## 4 EFFECTS OF OIL IN THE SEA



Numerous research, academic, and industrial organizations throughout the world have contributed to knowledge of the effects of oil on the marine environment, and their research efforts have been increasing. Exxon Corporation scientists, to illustrate, identified some 100 worldwide projects on effects under way in 1982, with total annual funding of $12 million. This was a 60 percent increase in funding over 1976, when a similar survey was last made.

The 1985 National Academy of Sciences report expresses the consensus of experts on the effects of oil in the sea. Its principal conclusions, generally accepted by the scientific community, are as follows:

- Based on the evidence available, there has been no apparent irrevocable damage to marine resources on a broad oceanic scale by either chronic inputs of oil or occasional major oil spills.
- Where oil has had an effect, subsequent monitoring has shown indications of biological recovery.
- Most marine organisms can coexist with hydrocarbons when concentrations are very low (less than 100 ppb) and when oil is weathered.
- Marine organisms' absorption and assimilation of oil from food and/or water are universal. However, animals and, apparently, plants are able to clear their tissues by releasing the accumulated petroleum back into the water after the removal of the oil source.
- Petroleum can have a seriously adverse effect on local environments, particularly coastal areas, where the amount of petroleum released is relatively great, waters are shallow, and water currents tend to hold the oil closer to shore.
- There is no evidence to date of a deleterious impact on human health from releases of petroleum into the marine environment.

Similar conclusions were reported by Great Britain's Royal Commission on Environmental Pollution in 1981 and the United Nations' Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP) in 1978.

The effects of oil on marine organisms depend upon the type and volume of oil spilled, degree of dispersion of the oil, water circulation, oxygen concentration, nutrient (nitrogen, phosphorus) influx, and the types of marine organisms exposed.

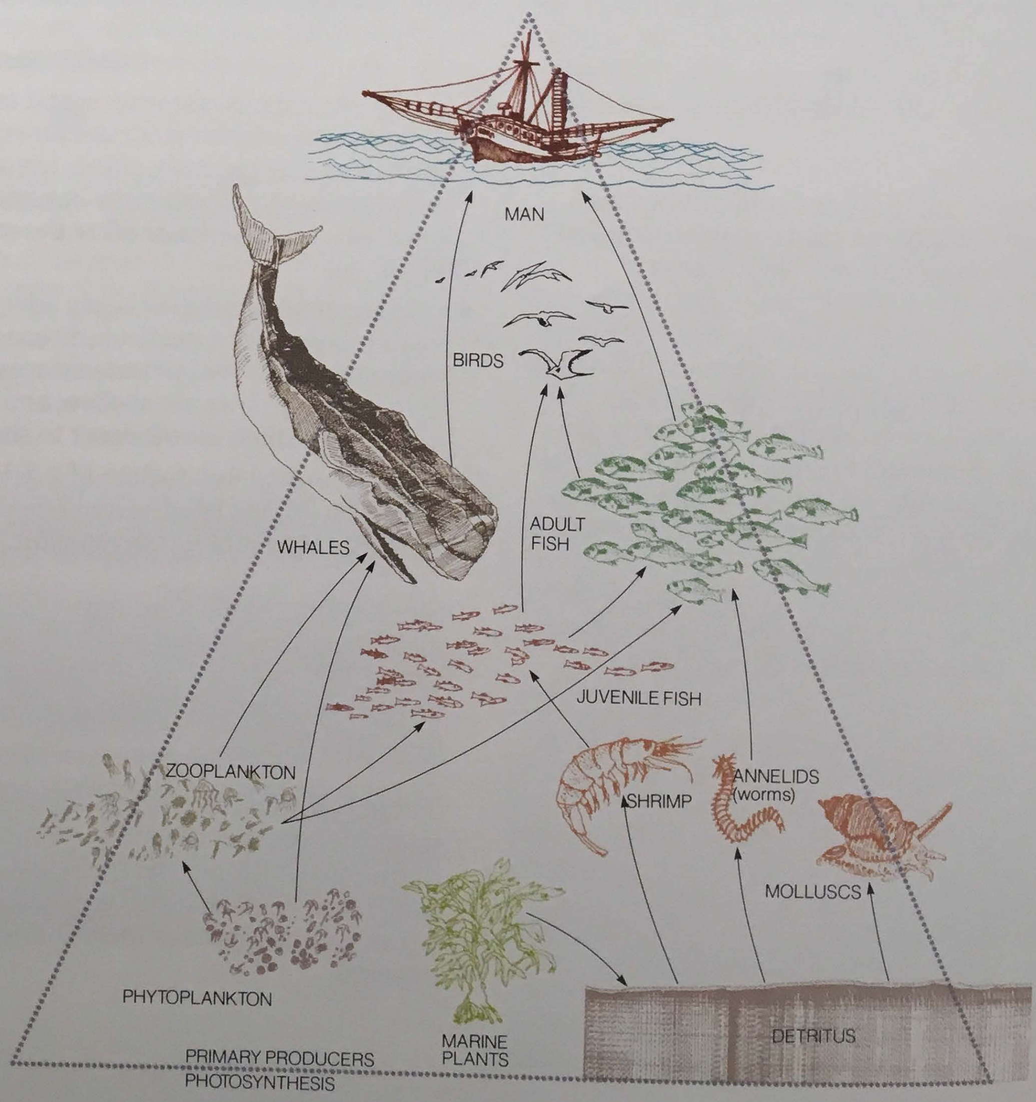
Figure 7 represents a generalized marine food web, showing at the lower left the minute plants or unicellular algae (phytoplankton) which drift, unattached, in the water column, and are the primary producers of organic matter. Phytoplankton form the foundation of the marine food chain by converting solar energy to the chemical energy of organic substances through photosynthesis.

Floating oil may reduce sunlight penetration, thus depressing rates of photosynthesis by phytoplankton in surface waters beneath the slick. Furthermore, the toxic effects of the oil in the water can cause depressed rates of photosynthesis, growth lags, and mortality, depending on the phytoplankton species and the type of oil. These effects on phytoplankton populations, however, are localized and transient. Photosynthesis by phytoplankton occurs continuously at a rapid rate. With abundant availability for recruitment of phytoplankton from adjacent waters, the threat of significant long-term impacts on these primary producers is very small.

Zooplankton are animals ranging in size from one-celled protozoa to large jellyfish. They are an important group because they include a substantial proportion of the juvenile forms of many marine animals which in the adult stage have economic importance (fish and shellfish). Field studies of the impacts on zooplankton at spill sites have documented mortality, external contamination by oil, tissue contamination, abnormal development, behavior alterations, and metabolic changes. As in the case of phytoplankton, such effects appear to be localized and short-lived due to rapid recruitment and regeneration of these invertebrates.

Figure 7

## Generalized Marine Food Web



Marine plants include large algal plants, such as kelp, inhabiting the open ocean and intertidal and subtidal environments, as well as marsh grass, mangroves, and seagrasses. Plants which occupy the intertidal zone between high and low tides are most at risk from spilled oil as they may be directly coated by oil stranded by a receding tide.

Primary concerns about the impact of oil on plant communities are not because of damage to the plants themselves. Marine plants have demonstrated the ability to recover from oil impact, once the oil has been removed or has biodegraded. These plant communities play a vital overall role in the habitat, however, and loss of plant cover can have significant, though temporary, impact on other organisms in the ecosystem.

Benthic animals, such as molluscs, annelids (worms), and shrimp, live on or in the bottom sediments, occupying the intertidal zone or the subtidal zone (always covered by a water column). Many representatives of benthic organisms are also commercially important, including oysters, clams, crabs, and lobsters. Some, such as oysters, are filter feeders, filtering and ingesting suspended food particles from the water. Other benthic animals, such as annelids, are deposit feeders which collect food particles that settle on the sediment surface or obtain food from organic material (detritus) in the sediments.

The intertidal benthic organisms are the most vulnerable to oil impact. Damage to these animals may result from direct smothering by heavy oiling, toxicity of the lighter fractions of the oil, or ingestion of oil-sediment particles. The subtidal benthic organisms can also be impacted primarily by sedimented oil. Benthic animals may be contaminated or tainted by moderate or low level exposure to petroleum, but many, in particular the filter feeders, will naturally cleanse themselves when the source of contamination is removed.

The early life stages of fish are relatively sensitive to oil in the water column. Effects include the failure of eggs to hatch, larval deformities, and mortalities. In view of the very high rate of natural mortality among these life stages, however, the impacts of an oil spill are generally seen only in the local area, and the spill site recovers relatively soon after the oil is removed or dispersed.

Adult fish are mobile and generally avoid areas of heavy oil contamination. Dissolved or dispersed hydrocarbons, however, may be taken up through their gills or ingested, and accumulate in the liver, gall bladder, and stomach. Fish have the capability to metabolize hydrocarbons and can excrete both parent hydrocarbons and metabolites, purging themselves completely within weeks after exposure.

The effects of oil on marine mammals have not been investigated as well as those on other marine organisms. Experiments have indicated these animals also avoid oil slicks. Whether oil adheres to them depends on the texture of their skin or fur. Oil is unlikely, therefore, to adhere to such marine mammals as walruses, whales, and porpoises.

Direct impacts of oil on birds include loss of insulation, buoyancy, and flying ability resulting from oiled plumage. These, in turn, may cause hypothermia (unusually low body temperature), drowning, decreased feeding ability, and mortality. The significance of bird mortalities, as those of other organisms, should be considered in the context of their population level, which is influenced by the species' abundance, distribution, reproductive potential, and exposure to other stress. Most concern is expressed over the potential for complete loss of an important colony or extinction of a rare species, and in most areas the possibility of such an event is very remote. In cases where the potential impacts are great, measures are available (e.g., chemical dispersion, bird scaring devices, deflection booming) to help reduce exposure of the birds to oil.

As to the effects of petroleum on human health, the primary concern centers on the possible ingestion of polycyclic aromatic hydrocarbons (PAHs), some of which are known to be in tainted seafood. The United Nations report cited earlier (page 9) notes that PAHs in seafood are not the only source of potentially carcinogenic material for humans. Other sources include a full range of foods, from plant products to meats—especially smoked foods.

The 1985 NAS report suggests, based on the limited information available on the metabolism of PAHs by humans, that the majority of PAHs are rapidly absorbed and excreted and do not tend to accumulate. The NAS report concludes that there is no evidence to date of a deleterious impact of petroleum on human health via the marine environment.

Since 1980, there has been considerable worldwide research, at an estimated cost of about $4 million per year, to compare the environmental effects of chemically dispersing oil slicks with leaving the slicks untreated. Among the findings was confirmation that chemical dispersion prevents the severe impacts caused by oil coating important resources. It prevents the oiling of birds, marine mammals, and other organisms common to the sea surface. Similarly, oil that is chemically dispersed before impacting a shoreline will neither smother intertidal plants and animals nor adhere to the shoreline substrate.

The greatest benefit of using chemical dispersants in oil spill response may be in protecting sensitive, highly productive ecosystems, such as mangroves, coral reefs, and benthic intertidal and subtidal communities. Studies in Panama, Bermuda, and Maine, reported at the 1985 Oil Spill Conference in Los Angeles, all indicate that chemical dispersants can be useful in protecting these ecosystems from the impact of oil spills.

## 5 SUMMARY

- The most recent estimate of the input of petroleum hydrocarbons into the sea, published in 1985, is about 3.2 million metric tons per annum (mta). This is down significantly from the 6.1 million mta estimate published 10 years earlier.
- Hydrocarbons, some identical to those found in petroleum, are also generated by marine organisms.
- Most surface and near-surface waters in the open oceans contain petroleum hydrocarbons ranging from 1 to 10 parts per billion (ppb). Coastal waters near harbors and industrialized areas contain higher levels, up to 100 ppb.
- When petroleum hydrocarbons are released into the marine environment, many physical, chemical, and biological processes affect the oil, including spreading, drift, evaporation, dissolution, dispersion, emulsification, sedimentation, biodegradation, and photooxidation. Evaporation, biodegradation, and, to a lesser extent, photooxidation are the only processes that actually cleanse the oil from the sea. However, some of the other processes, such as dissolution and dispersion, do help to make the oil more available for biodegradation and photooxidation. Biologically produced hydrocarbons no doubt are affected by the same processes.
- Evaporation is the most important initial process in removing petroleum hydrocarbons from the ocean's surface. Estimates from major oil spills, as well as experimental data, indicate that evaporation may be responsible for the loss of up to 50 percent of an oil slick.
- Another important process in the dissipation of petroleum hydrocarbons is dispersion. Dispersion can proceed naturally or can be enhanced by application of chemical surfactants.
- Biodegradation is an important decomposition process for removing either petroleum or biologically produced hydrocarbons from the ocean, particularly if the hydrocarbons are in a dispersed phase brought about naturally or by use of chemicals.
- Based on the evidence available, there has been no evident irrevocable damage to marine resources on a broad oceanic scale, by either chronic inputs of oil or occasional major oil spills.
- Where oil has had an effect, subsequent monitoring has shown biological recovery taking place.
- Most marine organisms can coexist with hydrocarbons when concentrations are very low (less than 100 ppb) and when oil is weathered.
- Marine organisms' absorption and assimilation of oil from food and/or water are universal. However, animals and, apparently, plants are able to clear their tissues by purging the accumulated petroleum back into the water after the removal of the oil source.
- Petroleum can have a seriously adverse effect on local environments, particularly coastal areas, where the amount of petroleum released is relatively great, waters are shallow, and current systems tend to hold the oil closer to shore.
- The greatest benefit of using chemical dispersants in oil spill response may very well be in protecting sensitive, highly productive ecosystems.
- There is no evidence to date of a deleterious impact on human health from releases of petroleum into the marine environment.

Additional copies of this and the following papers in the Exxon Background Series are available upon request from the Public Affairs Department, Exxon Corporation, 1251 Avenue of the Americas, New York, New York 10020-1198.

*How Much Oil and Gas?*

*Improved Oil Recovery*

*Middle East Oil and Gas*

*The Offshore Search for Oil and Gas*

*Tankers and the Flags They Fly*